

VIIRS Global Land Surface Phenology Product User Guide

Version 1.1

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DOCUMENT HISTORY DOCUMENT REVISION LOG

The Document Revision Log identifies the series of revisions to this document since the baseline release. Please refer to the above page for version number information.

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Revision No.	Date	Revision Originator Project Group
1.0	10/3/2016	First draft preparation
1.0	07/20/2017	Modified version for delivery
1.0	09/25/2019	Added description for CMG phenology
1.1	01/17/2020	Added differences from MODIS product (MCD12Q2 C6), changed VNP12Q2 to VNP22Q2 and VNP12C2 to VNP22C2, and added “_1” and “_2” to the data field name for each attribute in order to separate cycle 1 and cycle 2. Several additional edits throughout to add clarity and adjust graphics.

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1. Products

This is an external user guide document describing the NASA Visible Infrared Imaging Radiometer Suite (VIIRS) Global Land Surface Phenology (GLSP) product and output format. The VIIRS LSP product algorithm was developed at South Dakota State University and Boston University and the product is operationally produced and distributed at NASA's Goddard Space Flight Center.

1.1. Product Overview

The VIIRS GLSP product generates phenological metrics of individual vegetation growing cycles on the vegetated land surface at a spatial resolution of 500m across the globe. The 500m product is generated using daily VIIRS Nadir BRDF (bidirectional reflectance distribution function)-Adjusted Reflectance (NBAR) and ancillary data from VIIRS land surface temperature (LST), snow cover, and land cover type at each pixel as inputs. The VIIRS NBAR is used to generate time series of two-band enhanced vegetation index (EVI2) that characterizes temporal vegetation phenology development. The product contains seven metrics describing the occurrence timings of vegetation phenological events. As a supplement to the phenological timings, it also includes five metrics related to the range, change rate, and summation of vegetation greenness (EVI2) calculated from VIIRS surface reflectance data. Moreover, the GLSP product also provides seven metrics to quantify the quality of phenological timing and greenness measurements in each pixel.

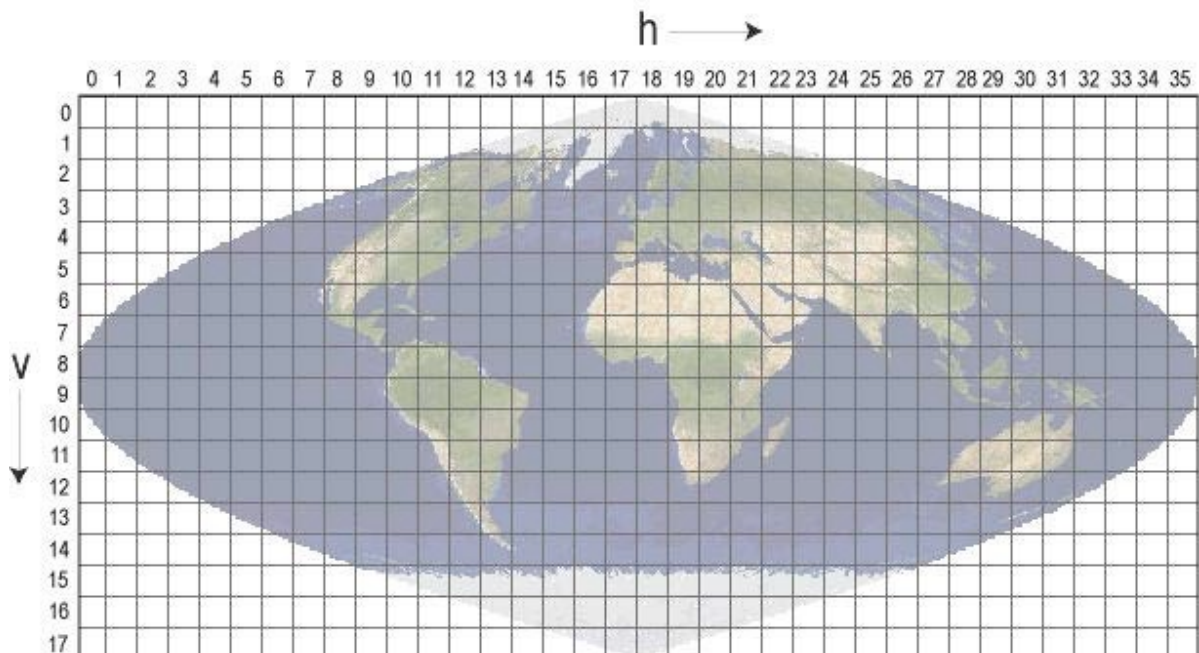


Figure 1. VIIRS Sinusoidal “10-degree” tile system. GLSP distributes in 286 tiles with vegetated pixels located between 60°S to 80°N.

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The 500m VIIRS GLSP product is a level 3 product and follows the structure and file format of the high level global VIIRS data. The data are saved in HDF-EOS5 (Hierarchical Data Format - Earth Observing System, built on HDF5) file format in the Sinusoidal map projection. Based on this projection, the GLSP product is recorded in tiles that are approximately $10^{\circ} \times 10^{\circ}$ in size on the Earth surface. Each tile is assigned a horizontal (H) and vertical (V) coordinate, ranging from 0 to 35 and 0 to 17, respectively (Figure 1). The tile in the upper left (i.e. northernmost and westernmost) corner is numbered (0,0). The GLSP product is distributed in 286 land tiles located between 60°S to 80°N . At a spatial resolution of 500m GLSP, each tile is composed of 2400 columns and 2400 rows. It produces one file of phenological metrics for each tile once a year.

The GLSP product is also provided in the Climate Modeling Grid (CMG). CMG datasets provide global coverage in a Geographic Lat/Lon projection at a resolution of 0.05 degrees ($\sim 5\text{km}$). In order to assure continuity of VIIRS GLSP CMG with the phenology measurements from the NASA Land Long Term Data Record (LTDR) AVHRR-MODIS (since 1982), VIIRS GLSP CMG uses daily VNP09CMG as input. The ancillary inputs include climatology LST generated from the collection 5 MODIS 8-day LST CMG from 2002-2016 and MODIS land cover CMG product for 2007. VIIRS GLSP CMG product provides one file every year with a data size of 7200 columns and 3600 rows. The phenological metrics in CMG product are the same as those in 500m product.

1.2. Product History

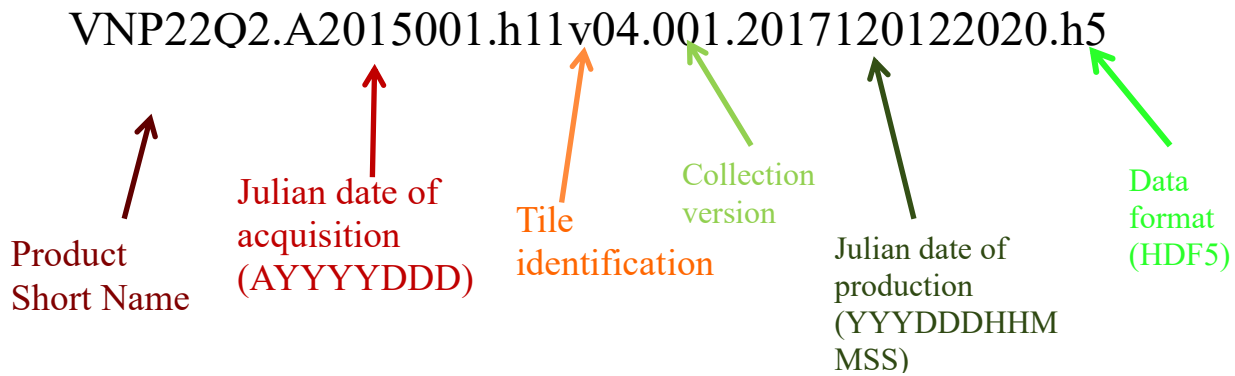
VIIRS GLSP is a continuous phenology product to replace and provides continuity with the MODerate-resolution Imaging Spectroradiometer (MODIS) product. The MODIS phenology product was part of the MODIS Land Cover/Dynamics product, MCD12Q2, provided at a spatial resolution of 500m. MCD12Q2 has been produced using algorithms developed at Boston University since 2001 based on the observations from both Terra and Aqua MODIS, providing observations twice a day in daytime with more chances to obtain cloud-free data than VIIRS observations. In the MCD12Q2 product, the phenological metrics are stored in an HDF4 file for each tile. Because MODIS is aging, VIIRS GLSP will replace MCD12Q2 to continue monitoring global phenology variation. VIIRS GLSP is produced using a time series of daily VIIRS observations and contains well qualified confidence of phenology detections. The output files are written in the HDF-EOS5 format.

1.3. Product Access

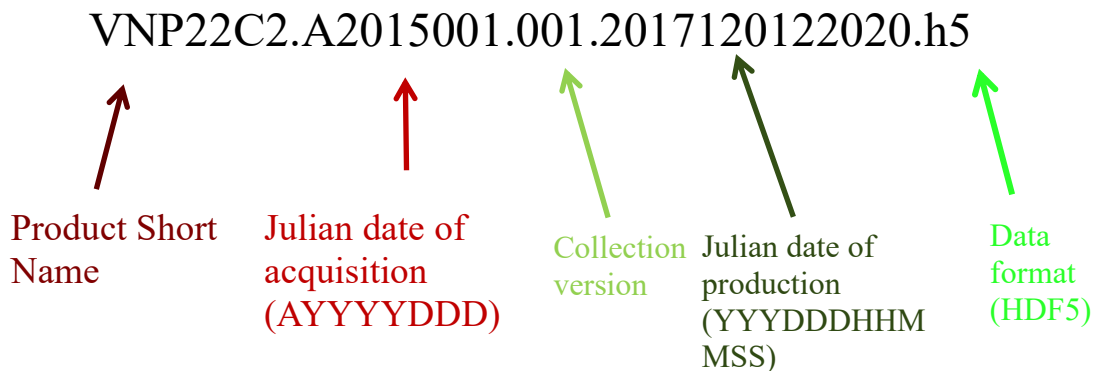
VIIRS GLSP output files are made available to users free of charge. Like most of the VIIRS land products, VIIRS GLSP can be obtained from the Land Processes Distributed Active Archive Center (LPDAAC) (<https://lpdaac.usgs.gov/>).

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The VIIRS GLSP 500m resolution tile has the following file naming convention:



The VIIRS GLSP CMG product has the following file naming convention:



2. Detailed Product Descriptions

The standard VIIRS GLSP product is produced yearly at a spatial resolution of 500m, as well as the CMG. The product contains six phenological transition dates (Table 1):

- Onset_Greenness_Increase: the date of onset of greenness increase (greenup onset, start of growing season, or start of spring);
- Onset_Greenness_Maximum: the date at which canopy greenness approaches its seasonal maximum (maturity onset or end of spring);
- Onset_Greenness_Decrease: the date at which canopy greenness begins to decrease (senescence onset or start of fall);
- Onset_Greenness_Minimum: the date at which canopy greenness reaches a minimum (dormancy onset, end of growing season, or end of fall);

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- **Date_Mid_Greenup_Phase:** the date at a mid-greenup phase (mid-greenup phase or middle of spring);
- **Date_Mid_Senescence_Phase:** the date at a mid-senescence phase (mid-senescent phase or middle of fall).

The product also includes another timing metric, the growing season length (**Growing_season_length**), which quantifies the time period between the dates of greenup onset and dormancy onset. The greenness related metrics in the GLSP product are:

- **EVI2_Onset_Greenness_Increase:** the EVI2 value at greenup onset, which is close to the minimum greenness during a growing season;
- **EVI2_Onset_Greenness_Maximum:** the EVI2 value at maturity onset, which is close to the maximum greenness during a growing season;
- **EVI2_Growing_Season_Area:** the integrated EVI2 during a growing season (from greenup onset to dormancy onset);
- **Rate_Greenness_Increase:** the rates of change in EVI2 values during a greenup phase;
- **Rate_Greenness_Decrease:** the rates of change in EVI2 values during a senesce phase.

Table 1. Scientific Data Sets of the VIIRS GLSP product.

Scientific Data Sets	Units	Bit Type	Fill Value	Valid Range	Scale Factor
Onset_Greenness_Increase	Day	16-bit unsigned integer	32767	1-32766	DOY=file data - (given year-2000)*366
Onset_Greenness_Maximum					
Onset_Greenness_Decrease					
Onset_Greenness_Minimum					
Date_Mid_Greenup_Phase					
Date_Mid_Senescence_Phase					
Growing_Season_Length	Number of days	16-bit unsigned integer	32767	1-366	N/A
EVI2_Onset_Greenness_Increase	EVI2	16-bit unsigned integer	32767	1-10000	EVI2=file data*0.0001
EVI2_Onset_Greenness_Maximum	EVI2				
EVI2_Growing_Season_Area	EVI2	16-bit unsigned integer	32767	1-32766	EVI2=file data*0.01
Rate_Greenness_Increase	EVI2 per day	16-bit unsigned integer	32767	1-32766	EVI2/day=file data*0.0001
Rate_Greenness_Decrease					
Greenness_Agreement_Growing_Season	Dimensionless	8-bit unsigned integer	255	0-100	N/A
PGQ_Growing_Season					
PGQ_Onset_Greenness_Increase					
PGQ_Onset_Greenness_Maximum					
PGQ_Onset_Greenness_Decrease					
PGQ_Onset_Greenness_Minimum					
GLSP_QC	Dimensionless	8-bit unsigned integer	255	0-100	N/A

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The confidence of phenology detections is provided in six data sets (Table 1):

- **Greenness_Agreement_Growing_Season:** the EVI2 agreement between modeled values and raw observations with good quality (cloud free observations) during a vegetation growing season;
- **PGQ_Growing_Season:** the proportion of good quality (PGQ) of VIIRS observations during a vegetation growing season, in which the good quality observations are counted as the number of three 3-day moving windows that contain good quality observations;
- **PGQ_Onset_Greenness_Increase:** PGQ around greenup onset, which is calculated as the proportion of 3-day good observations during the periods of 3 3-day EVI2 composite before and after the greenup onset;
- **PGQ_Onset_Greenness_Maximum:** PGQ around maturity onset, which is calculated as the proportion of 3-day good observations during the periods of 3 3-day EVI2 composite before and after the maturity onset;
- **PGQ_Onset_Greenness_Decrease:** PGQ around senescence onset, which is calculated as the proportion of 3-day good observations during the periods of 3 3-day EVI2 composite before and after the senescence onset;
- **PGQ_Onset_Greenness_Minimum:** PGQ around dormancy onset, which is calculated as the proportion of 3-day good observations during the periods of 3 3-day EVI2 composite before and after the dormancy onset.

The last data set is quality control (QC, GLSP_QC). QC is produced at each pixel based on overall quality assurance (QA), which specifies the overall quality of the product. Several bit fields are passed through from the corresponding VIIRS Albedo/NBAR (VNP43I4 and VNP43I2) products, particularly the land/water mask. The bit patterns are parsed from right to left and the interpretation of bit-strings is presented in Table 2.

Table 2. Values of GLSP_QC (8-bit)

Bit No.	Parameter Name	Bit Comb	GLSP_QC
0-2	Mandatory Quality	000	0=processed, good quality
		001	1= processed, other quality
		010	2=processed, backup algorithm
		011	3= not processed, bad quality
		100	4=not processed, other
3-4	TBD	TBD	TBD
5-7	Land/water mask	000	0 = Shallow ocean
		001	1 = Land (Nothing else but land)
		010	2 = Ocean coastlines and lake shorelines
		011	3 = Shallow inland water
		100	4 = Ephemeral water
		101	5 = Deep inland water
		110	6 = Moderate or continental ocean
		111	7 = Deep ocean

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2.1. Vegetation growing cycle and data cycle in the output GLSP product

The cycle of the vegetation growing season differs geographically, especially between Northern and Southern Hemispheres (Figure 2). Further, vegetation growth can have one or more growing cycles (or parts of growing cycles) during a 12-month period (calendar). Each full vegetation growing cycle starts from greenup onset and ends at dormancy onset. To record possible multiple growing cycles, the algorithm used for this product allows to record a maximum of two data layers for each phenological event in a given calendar year. If the product data are recorded based on vegetation growing cycles, which are the first and second data layers for the first and second growing cycles, separately, any phenological events in the third vegetation growing cycle are unable to be recorded in the given year (such as Figure 2f-h). To fully record the vegetation growing cycles without increasing

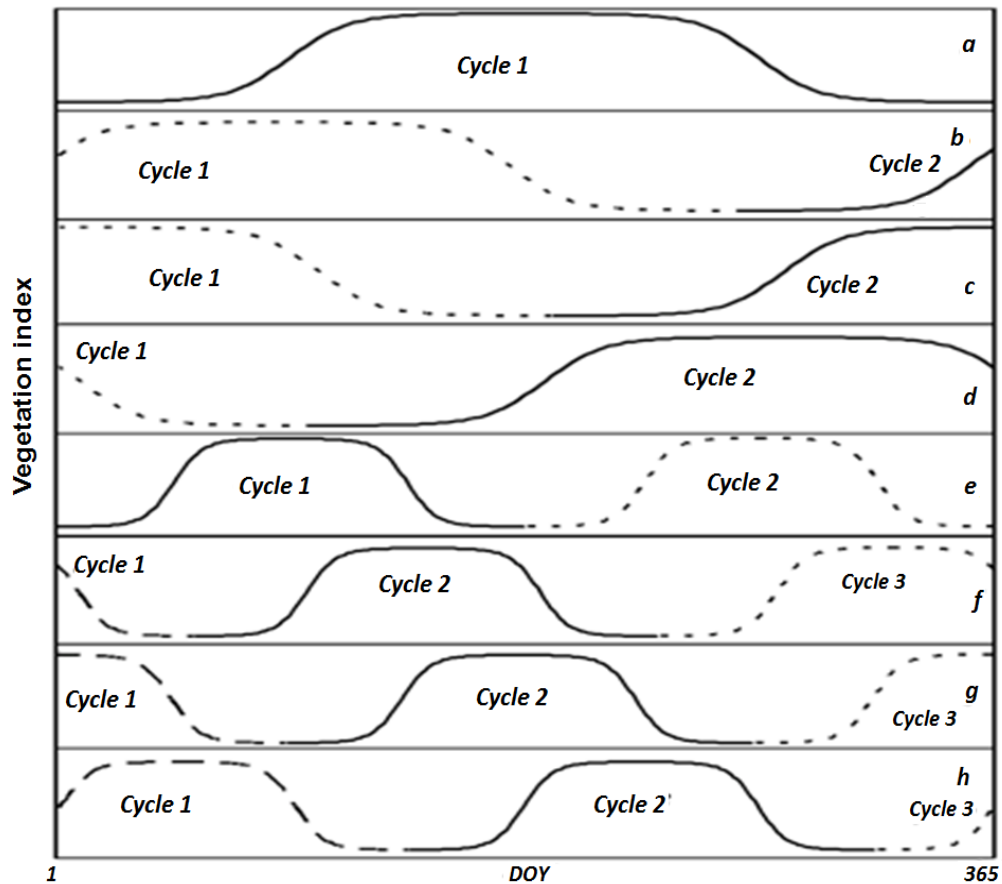


Figure 4. Characteristics of vegetation growing cycles during a 12-month period (current year).

the data size of output file, the VIIRS GLSP product records data cycles that are different from the vegetation growing cycles. The data cycles are defined based on the four key phenological transition dates (greenup onset, maturity onset, senescence onset, and dormancy onset). In other words, starting from January 1, the part of EVI2 curve contains the first four key phenological transition dates as the first data cycle no matter which phenological event appears first (Figure 3). As a result, the two data layers (data cycles: Cycle 1 and Cycle 2 in the GLSP product) can record phenological information in

parts of the third vegetation growing cycle, which are common in Southern Hemisphere. All other phenological metrics related to phenological dates are recorded in the same way as the four key phenological dates. Fill values are used for data cycle 2 if no vegetation phenological events occur (such as Figure 3a-d). It should be noted that the rate of change in EVI2 during the greenup phase is recorded only accompanying with the appearance of greenup onset, and the rate of change in EVI2 during the senescence phase is recorded with the appearance of senescence onset.

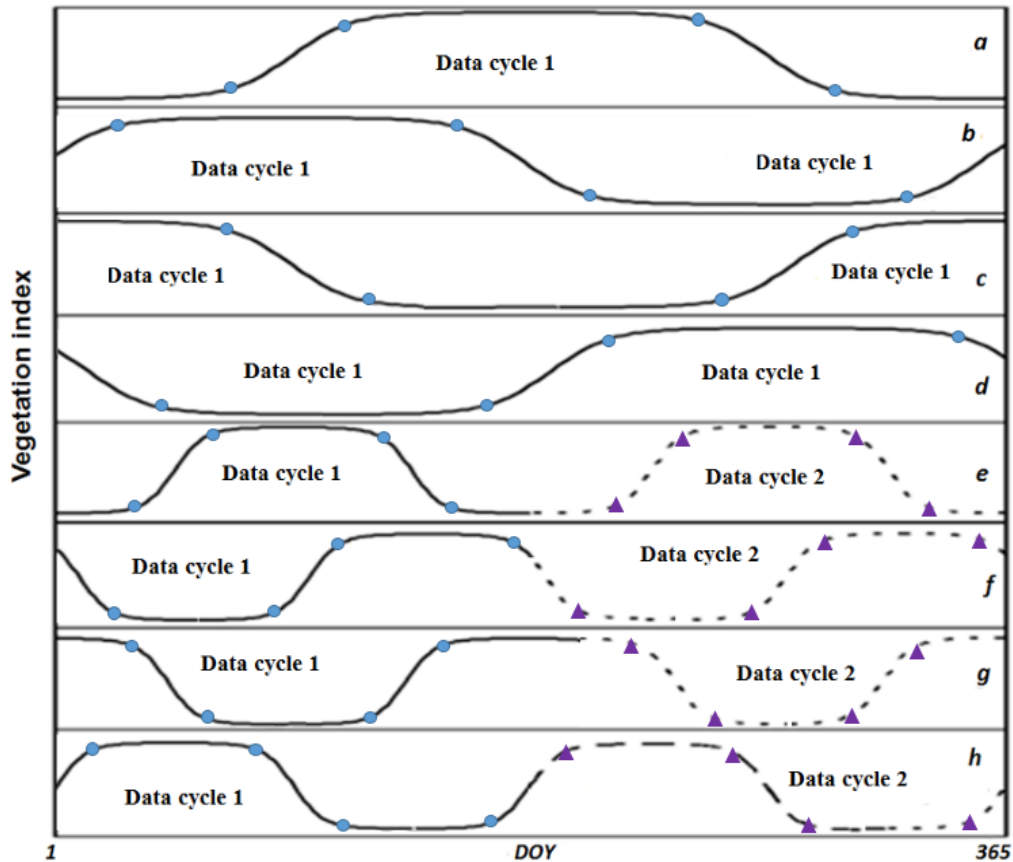


Figure 5. Data cycles recorded in the VIIRS GLSP product during a calendar year. Solid line represents data cycle 1 while dashed line represents data cycle 2. The solid dots are the four phenological dates in the data cycle 1 (first data layer) and solid triangles are the four phenological dates in the data cycle 2 (second data layer).

However, the phenological metrics related to the entire vegetation growing cycle are more complex. These metrics include growing season length, growing season integrated EVI2, EVI2 model agreement, proportion of good quality (PGQ) VIIRS observations, and quality control (QC). They are recorded in the first data cycle if the dormancy onset occurs in the current year but the corresponding greenup onset in the growing cycle appears in the preceding year (Figure 4). If an entire growing season occurs in the current year, the phenological metrics associated with the vegetation growing season are simply recoded in the first data cycle or the second data cycle.

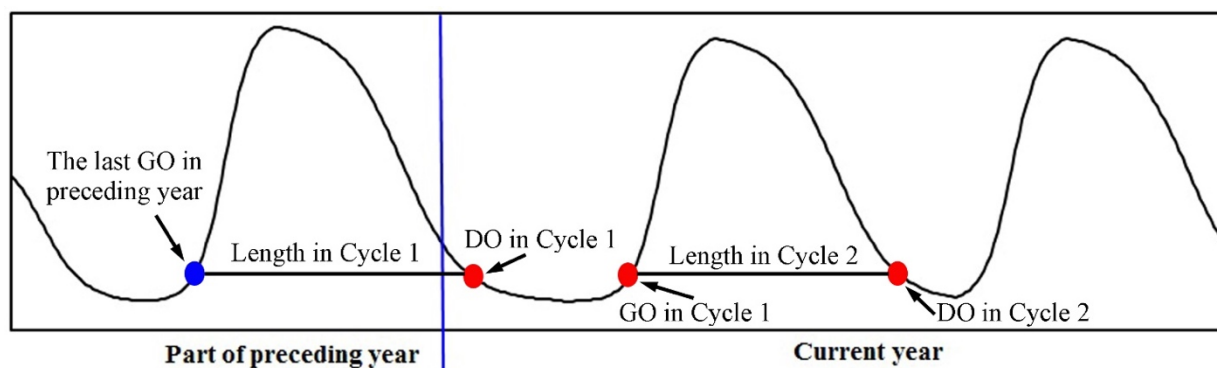


Figure 7. An example of recording metrics related to growing season length if a growing season spans parts of preceding year and current year. Cycle 1 refers to the first data cycle (layer) and Cycle 2 refers to the second one in the product. GO - greenup onset and DO - dormancy onset.

2.2. Metadata information

An example of VNP22Q2.A2015001.h11v04.001.2017120122020.h5:

```
GROUP=SwathStructure
END_GROUP=SwathStructure
GROUP=GridStructure
  GROUP=GRID_1
    GridName="Cycle 1"
    XDim=2400
    YDim=2400
    UpperLeftPointMtrs=(-7783653.637667,5559752.598333)
    LowerRightMtrs=(-6671703.118000,4447802.078667)
    Projection=HE5_GCTP_SNSOID
    ProjParams=(6371007.181000,0,0,0,0,0,0,0,0,0,0)
    SphereCode=-1
  GROUP=Dimension
    OBJECT=Dimension_1
      DimensionName="YDim"
      Size=2400
    END_OBJECT=Dimension_1
    OBJECT=Dimension_2
      DimensionName="XDim"
      Size=2400
    END_OBJECT=Dimension_2
  END_GROUP=Dimension
GROUP=DataField
  OBJECT=DataField_1
    DataFieldName="Onset_Greenness_Increase_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
```

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```
END_OBJECT=DataField_1
OBJECT=DataField_2
    DataFieldName="Onset_Greenness_Maximum_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_2
OBJECT=DataField_3
    DataFieldName="Onset_Greenness_Decrease_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_3
OBJECT=DataField_4
    DataFieldName="Onset_Greenness_Minimum_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_4
OBJECT=DataField_5
    DataFieldName="Date_Mid_Greenup_Phase_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_5
OBJECT=DataField_6
    DataFieldName="Date_Mid_Senescence_Phase_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_6
OBJECT=DataField_7
    DataFieldName="Growing_Season_Length_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_7
OBJECT=DataField_8
    DataFieldName="EVI2_Onset_Greenness_Increase_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_8
OBJECT=DataField_9
    DataFieldName="EVI2_Onset_Greenness_Maximum_1"
    DataType=H5T_NATIVE_USHORT
```

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```
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
END_OBJECT=DataField_9
OBJECT=DataField_10
    DataFieldName="EVI2_Growing_Season_Area_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_10
OBJECT=DataField_11
    DataFieldName="Rate_Greenness_Increase_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_11
OBJECT=DataField_12
    DataFieldName="Rate_Greenness_Decrease_1"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_12
OBJECT=DataField_13
    DataFieldName="Greenness_Agreement_Growing_Season_1"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_13
OBJECT=DataField_14
    DataFieldName="PGQ_Growing_Season"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_14
OBJECT=DataField_15
    DataFieldName="PGQ_Onset_Greenness_Increase_1"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_15
OBJECT=DataField_16
    DataFieldName="PGQ_Onset_Greenness_Maximum_1"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_16
OBJECT=DataField_17
```

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```
DataFieldName="PGQ_Onset_Greenness_Decrease_1"
DataType=H5T_NATIVE_UCHAR
DimList=("YDim","XDim")
MaxdimList=("YDim","XDim")
END_OBJECT=DataField_17
OBJECT=DataField_18
DataFieldName="PGQ_Onset_Greenness_Minimum_1"
DataType=H5T_NATIVE_UCHAR
DimList=("YDim","XDim")
MaxdimList=("YDim","XDim")
END_OBJECT=DataField_18
OBJECT=DataField_19
DataFieldName="GLSP_QC_1"
DataType=H5T_NATIVE_UCHAR
DimList=("YDim","XDim")
MaxdimList=("YDim","XDim")
END_OBJECT=DataField_19
END_GROUP=DataField
GROUP=MergedFields
END_GROUP=MergedFields
END_GROUP=GRID_1
GROUP=GRID_2
GridName="Cycle 2"
XDim=2400
YDim=2400
UpperLeftPointMtrs=(-7783653.637667,5559752.598333)
LowerRightMtrs=(-6671703.118000,4447802.078667)
Projection=HE5_GCTP_SNSOID
ProjParams=(6371007.181000,0,0,0,0,0,0,0,0,0,0)
SphereCode=-1
GROUP=Dimension
OBJECT=Dimension_1
DimensionName="YDim"
Size=2400
END_OBJECT=Dimension_1
OBJECT=Dimension_2
DimensionName="XDim"
Size=2400
END_OBJECT=Dimension_2
END_GROUP=Dimension
GROUP=DataField
OBJECT=DataField_1
DataFieldName="Onset_Greenness_Increase_2"
DataType=H5T_NATIVE_USHORT
DimList=("YDim","XDim")
MaxdimList=("YDim","XDim")
```

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```
END_OBJECT=DataField_1
OBJECT=DataField_2
    DataFieldName="Onset_Greenness_Maximum_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_2
OBJECT=DataField_3
    DataFieldName="Onset_Greenness_Decrease_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_3
OBJECT=DataField_4
    DataFieldName="Onset_Greenness_Minimum_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_4
OBJECT=DataField_5
    DataFieldName="Date_Mid_Greenup_Phase_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_5
OBJECT=DataField_6
    DataFieldName="Date_Mid_Senescence_Phase_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_6
OBJECT=DataField_7
    DataFieldName="Growing_Season_Length_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_7
OBJECT=DataField_8
    DataFieldName="EVI2_Onset_Greenness_Increase_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_8
OBJECT=DataField_9
    DataFieldName="EVI2_Onset_Greenness_Maximum_2"
    DataType=H5T_NATIVE_USHORT
```


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```
        DimList=("YDim","XDim")
        MaxdimList=("YDim","XDim")
END_OBJECT=DataField_9
OBJECT=DataField_10
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    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_10
OBJECT=DataField_11
    DataFieldName="Rate_Greenness_Increase_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_11
OBJECT=DataField_12
    DataFieldName="Rate_Greenness_Decrease_2"
    DataType=H5T_NATIVE_USHORT
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_12
OBJECT=DataField_13
    DataFieldName="Greenness_Agreement_Growing_Season_2"
    DataType=H5T_NATIVE_UCHAR
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    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_13
OBJECT=DataField_14
    DataFieldName="PGQ_Growing_Season_2"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_14
OBJECT=DataField_15
    DataFieldName="PGQ_Onset_Greenness_Increase_2"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_15
OBJECT=DataField_16
    DataFieldName="PGQ_Onset_Greenness_Maximum_2"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_16
OBJECT=DataField_17
```

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```
DataFieldName="PGQ_Onset_Greenness_Decrease_2"
DataType=H5T_NATIVE_UCHAR
DimList=("YDim","XDim")
MaxdimList=("YDim","XDim")
END_OBJECT=DataField_17
OBJECT=DataField_18
    DataFieldName="PGQ_Onset_Greenness_Minimum_2"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_18
OBJECT=DataField_19
    DataFieldName="GLSP_QC"
    DataType=H5T_NATIVE_UCHAR
    DimList=("YDim","XDim")
    MaxdimList=("YDim","XDim")
END_OBJECT=DataField_19
END_GROUP=DataField
GROUP=MergedFields
END_GROUP=MergedFields
END_GROUP=GRID_2
END_GROUP=GridStructure
GROUP=PointStructure
END_GROUP=PointStructure
GROUP=ZaStructure
END_GROUP=ZaStructure
END
```

2.3. Data groups and datasets

There are two root groups in the GLSP HDF-EOS5 output file. The “GRIDS”, in the “HDFEOS” group, contain all the Scientific Data Sets. The data in Cycle 1 and Cycle 2 are two members of “GRIDS”. The “HDFEOS INFORMATION” group includes metadata information (Figure 5).

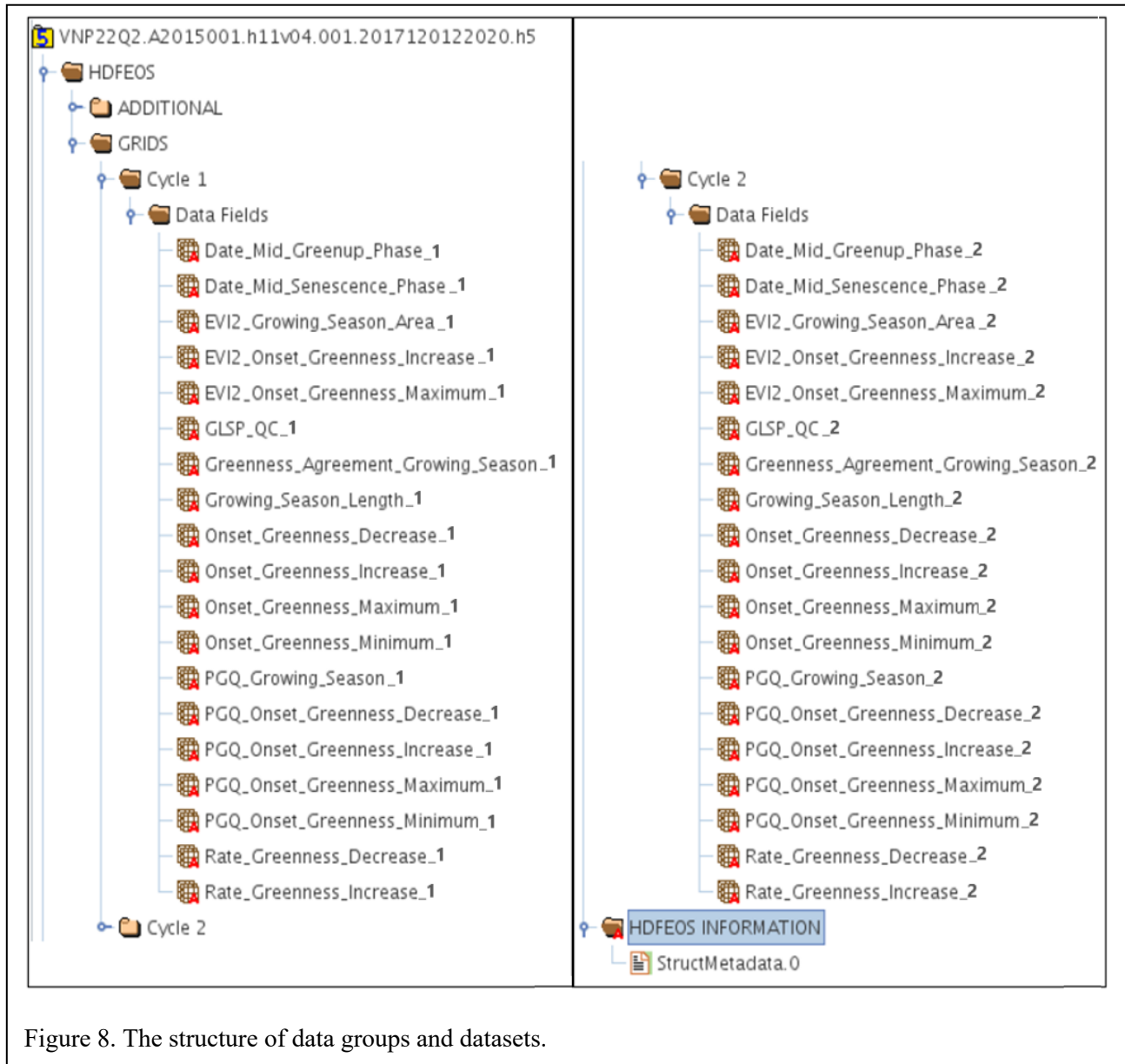


Figure 8. The structure of data groups and datasets.

3. Algorithm Description

3.1. Detection of phenological metrics

VIIRS GLSP is produced using the Hybrid Piecewise Logistic Model (HPLM)-Land Surface Phenology Detection (LSPD) algorithm (Zhang 2015; Zhang et al. 2003; Zhang et al. 2018a). The technical details can be found in the Algorithm Theoretical Basis Document (ATBD) and the

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accuracy of the phenology detections are evaluated by comparison with PhenoCam (<https://phenocam.sr.unh.edu/webcam/>) data and Landsat time series (Zhang et al. 2018b; Moon et al. 2019). The HPLM-LSPD algorithm is briefly described here. Inputs of the HPLM-LSPD algorithm are VIIRS NBAR (with data quality), snow cover, land surface temperature (LST), and land cover type. Specifically, daily VIIRS NBAR is used to calculate daily EVI2. The background EVI2 value at each pixel (i.e., the minimum snow-free value) is identified using the EVI2 values that are not contaminated by snow and cloud during the winter period defined using LST <278K. The data points associated with snow-covered surfaces are removed from the input time series and replaced with snow-free “background EVI2” values.

The annual temporal EVI2 trajectory is then reconstructed using the HPLM that describes biophysical progress of vegetation growth (Zhang 2015; Zhang et al. 2018a). To do this, raw EVI2 time series are smoothed using background EVI2 to remove snow contamination using a moving average. A Savitzky-Golay filter is used to reduce cloud and atmospheric impacts, and a local median filter is applied at the end to remove any remaining local outliers. The vegetation greenup phases and senescence phases are further separated using a moving slope algorithm along the smoothed EVI2 temporal trajectory. Transitions from the periods of ascending EVI2 to the periods of descending EVI2 are identified using changes from positive to negative slope, and vice versa. The HPLM is finally applied for fitting the EVI2 time series. By combining both favorable condition and stress condition in vegetation growth, the HPLM describes the temporal EVI2 trajectory using the following formula (Figure 9):

$$VI(t) = \begin{cases} \frac{c_1}{1 + e^{a_1 + b_1 t}} + VI_b & \text{Favorable growth condition} \\ \frac{c_2 + dt}{1 + e^{a_2 + b_2 t}} + VI_b & \text{Vegetation stress condition} \end{cases} \quad (1)$$

$$(2)$$

where t is time in the day of year (DOY), a is related to the vegetation growth time, b is associated with the rate of plant leaf development, c is the amplitude of EVI2 variation, d is a vegetation stress factor, and VI_b is the background EVI2 value. In order to determine whether the plant suffers from stress or not, the equations 1 and 2 are compared in fitting the temporal EVI2 observations and the function with better fitting is chosen.

From the reconstructed temporal trajectory, the timing of phenological transitions during the vegetation growing season are then extracted based on curvature change rate (Zhang et al. 2006; Zhang et al. 2003). Other phenological timing metrics and vegetation growth metrics are further calculated, which are listed in Table 1.

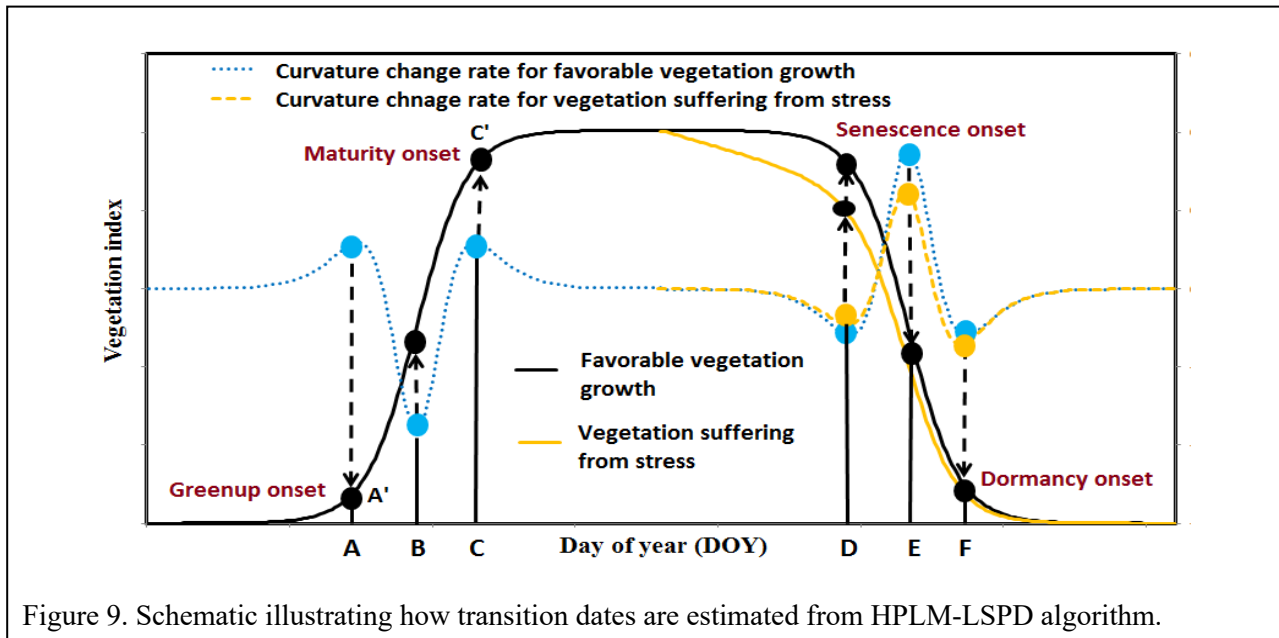


Figure 9. Schematic illustrating how transition dates are estimated from HPLM-LSPD algorithm.

3.2. Confidence of phenological metrics

The quality and confidence of GLSP metrics are strongly controlled by the quality of the time series of EVI2 observations. They are qualified using the model fit and the proportion of high quality data at each pixel. Goodness of model fit or agreement index (AI) is described using an index of model agreement (*Greenness_Agreement_Growing_Season* in Table 1) that is calculated from the differences between modeled values and satellite measurements with “good” quality during a growing season at each pixel (Willmott 1981; Zhang 2015; Zhnag et al. 2018a). The quality of satellite observations is inherited from VIIRS NBAR product.

Because the quality of the simulated EVI2 model at each pixel is strongly dependent on the number of good quality observations during a vegetation growing season (Zhang et al. 2009), the proportion of good quality (PGQ) EVI2 values for a given pixel is calculated for an entire growing season and around phenological phase transitions. The “*PGQ_Growing_Season*” parameter in Table 1 quantifies the quality of the simulated temporal trajectory within a growing season. In the calculation, a good observation is counted if there is one good value within a moving window of three 3-day EVI2 composites. Vegetation greenness temporal trajectory can be properly reconstructed if there is a good EVI2 observation within an 8-day period (Zhang et al. 2009).

The local EVI2 quality around the four key phenological dates that divide a vegetation growing season into four growing phases is also quantified to describe the confidence of the corresponding detections of phenological events. Simply, the local confidence is the proportion of good EVI2 during the three 3-day periods before and after the detected phenological timing. These four confidence parameters in Table 1 are *PGQ_Onset_Greenness_Increase*, *PGQ_Onset_Greenness_Maximum*,

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PGQ_Onset_Greenness_Decrease, and *PGQ_Onset_Greenness_Minimum*. Note that the low local confidence does not necessarily indicate the detected phenological timing is incorrect.

The overall mandatory quality (GLSP_QC in Table 1) in a specified growing season is controlled by both the proportion of good quality data (PGQ) and the agreement index (AI) of the EVI2 model, both of which scale from 0 to 100. From these two indices during a growing season, the overall quality assurance (QA) of phenological detections in VIIRS GLSP product is defined as:

- QA=0 (processed, good quality), if $PGQ \geq 60$ and $AI \geq 60$
- QA=1 (processed, other quality), if $20 \leq PGQ < 60$ or $AI < 60$
- QA=2 (processed, backup algorithm), if the length of consecutive missing EVI2 >30 days
- QA=3 (not processed, bad quality), if $PGQ < 20\%$
- QA=4 (not processed, other), if growing season amplitude in $EVI2 < 0.08$ in forests and $EVI2 < 0.02$ in other ecosystems

4. Related Web Sites

- VIIRS Land (<https://viirsland.gsfc.nasa.gov/index.html>)
- JPSS VIIRS (<https://www.star.nesdis.noaa.gov/jpss/VIIRS.php>)

5. Differences between VIIRS GLSP product (VNP22Q2) and MODIS Land Cover Dynamics (MCD12Q2 C6)

Users should be cautious about directly comparing the VIIRS GLSP product (VNP22Q2) with Collection 6 MODIS Land Cover Dynamics (MCD12Q2 C6). This is because the VNP22Q2 algorithm is similar to the MCD12Q2 C5 algorithm, but differs from the MCD12Q2 C6 algorithm in the following aspects. First, VNP22Q2 reconstructs the EVI2 time series using a physically-based HPLM, while MCD12Q2 C6 fits the EVI2 time series using a penalized cubic smoothing spline. Second, VNP22Q2 identifies phenological transition dates using the curvature change rate derived from the HPLM without any predefined thresholds involved, whereas MCD22Q2 C6 detects phenological dates using 15%, 50%, and 90% of EVI2 amplitude. Third, VNP22Q2 records the phenological metrics occurring within a given calendar year or product year (Figure 3), however, MCD12Q2 C6 records the metrics for the vegetation cycles for which the peak date falls within the calendar year of the product year. To better understand the MCD12Q2 C6 product, it is strongly recommended to read the user guide of MCD12Q2 C6 (https://lpdaac.usgs.gov/documents/218/mcd12q2_v6_user_guide.pdf).

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